LEVEL II

PROFESSIONAL PAPER 291 / October 1980

AD A091946

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15 NSF-SOC78-09473

18 CNA 19 PP-292

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SOME EXTENSIONS OF THE NERLOVE-PRESS MODEL

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I. INTRODUCTION

In two interesting papers, Nerlove and Press (1973, 1976) discuss methods of analyzing qualitative data with multivariate log-linear models. The purpose of the present paper is to suggest an alternative method of analyzing the problems that Nerlove and Press considered in terms of unobserved variables and dummy indicator variables. Nerlove and Press (1976) give two examples: agricultural practices of Phillippino farmers, and sexual attitudes of undergraduates of Northwestern University. In both these problems our main interest is not on which exogenous variables affect which main effects and interactions but on the determinants of an underlying unobservable variable ("adoption of modern agricultural methods", "sexual permissiveness" etc.) for which we have dummy indicator variables.

In this paper we will illustrate the methodology with respect to the example of the agricultural practices of Phillippino farmers. A similar procedure applies to the example on sexual attitudes of Northwestern University undergraduates and similar examples on models with unobservable variables with dummy indicators. In a subsequent section we will discuss the minor differences in approach in the different models. A general approach

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*We would like to thank Marc Nerlove for providing us the Mangahas data and for helpful comments on an earlier draft of the paper. Not all his suggestions could, however, be taken into account. Financial support from the National Science Foundation under grant SOC 78-09473 to the University of Florida is gratefully acknowledged. This paper was written whil[redacted] working under the professional development program at CN[redacted]

to such problems has been attempted in Muthen (1979) but our discussion of the Nerlove-Press examples, though less general, is easier to understand and will illustrate the type of problems one encounters in such models.

2. An Unobserved Variable Approach to Analyze Agricultural Practices

The first example that Nerlove and Press consider is that of agricultural practices of Phillippino farmers. They consider a model with 4 dichotomous endogenous variables defined as follows:

CHM = 1 if chemicals (fertilizers or insecticides) were used
= 0 otherwise.

LAND = 1 if mechanized method of land preparation was used
= 0 otherwise.

HYBRID = 1 if high yield variety (HYV) was used
= 0 otherwise.

PLNTWD = 1 if modern methods of planting and weeding were used
= 0 othewise.

There are also exogenous variables in their model. These are:

AGE = Farmer's age in years

SCHOOL = Highest educational level attained in years

OWNER = Tenure status, 1 if owner or part owner
0 othewise

AREA = Size of farm in hectares

IRRIG = 1 if farm in irrigated area
0 otherwise

CROP = 1 if the farm is irrigated but produced only one crop per year
= 0 if more than one crop was produced per year and the farm was irrigated.

COOP = 1 if the farmer is a cooperator

= 0 otherwise.

Regarding the two dichotomous variables IRRIG and CROP, it was pointed out by Nerlove that there is essentially one trichotomous variable which is whether the farm is located in an irrigated area, and if in an irrigated area, whether there is irrigation by pump or solely by gravity flow. This leads to three possible cases: the farm is located in a non-irrigated area, in which case only one crop can be produced per year; the farm is located in an irrigated area, but irrigation is by gravity flow, in which case only one crop can be produced per year. The farm is located in an irrigated area and pump irrigation is available. In this case two crops per year can be produced. The three cases are thus

IRRIG = 0 CROP = 1

IRRIG = 1 CROP = 1

IRRIG = 1 CROP = 0.

Nerlove and Press estimated a Goodman (1972) type model with the four main effects being linear functions of the exogenous variables and the six bivariate interactions being constant (not dependent on the exogenous variables). The higher interactions were assumed to be zero. Their empirical analysis showed IRRIG, COOP, and AREA as highly significant. PUMP was significant at 10% level but not 5% level and the remaining variables not significant at even the 20% level. It was rather disappointing to find that SCHOOLING and AGE were not significant.

The main objective of the analysis is to see whether adoption of modern agricultural methods depends on years of schooling, age, type of land-tenure, etc. To this end we can alternatively formulate the model as follows:

Let y be output

X^* the unobserved index of adoption of modern agricultural methods.

Corresponding to the 3 endogenous dichotomous variables CHM, LAND, HYBRID defined earlier (we omit PLNTWD from our analysis because the results reported by Nerlove and Press show that there are some problems with this variable), we can define three underlying unobserved indicator variables y_1^*, y_2^* and y_3^*, and three observed indicator variables I_1, I_2 and I_3 as follows.

$$\text{HYBRID} = 1 \iff I_1 = 1 \iff y_1^* \geq 0$$

$$\text{CHM} = 1 \iff I_2 = 1 \iff y_2^* \geq 0$$

$$\text{LAND} = 1 \iff I_3 = 1 \iff y_3^* \geq 0$$

We will denote the exogenous variables defined earlier (excluding Area) by Z. The variable Area, to be denoted by A, has been included as an explanatory variable in the output equation. We tried to include the variable A in Z, but its coefficient was always insiginificant. The equation system we consider is:

$$X^* = Z\gamma \tag{2.1}$$

$$y = \alpha + \beta X^* + \delta A + u \tag{2.2}$$

$$y_1^* = \alpha_1 + \beta_1 X^* + u_1 \tag{2.3}$$

$$y_2^* = \alpha_2 + \beta_2 X^* + u_2 \tag{2.4}$$

$$y_3^* = \alpha_3 + \beta_3 X^* + u_3 \tag{2.5}$$

Since X^* is unobservable, we need some normalization. Let us initially set $\beta = 1$ in equation (2.2). Substituting (2.1) in the other equations we get

$$y = \alpha + Z\gamma + \delta A + u \tag{2.6}$$

$$y_1^* = \alpha_1 + \beta_1 Z\gamma + u_1 \tag{2.7}$$

$$y_2^* = \alpha_2 + \beta_2 Z\gamma + u_2 \tag{2.8}$$

$$y_3^* = \alpha_3 + \beta_3 Z\gamma + u_3 \tag{2.9}$$

We will assume that y_1^*, y_2^*, y_3^* are independent indicators of good agricultural practice i.e., the unobserved variable X^*. This implies that the residuals u_1, u_2, u_3 are mutually independent. We will also assume that they are independent of the residual u in the output equation.

The assumption that y_1^*, y_2^* and y_3^* are independent indicators of the adoption of modern agricultural methods is a very strong assumption. In fact, in this example, it is almost surely invalid. We relaxed this assumption later,, but this did not produce any differences in the final conclusions. If the independence assumption is dropped, we have to use the multivariate probit methods for estimation purposes. With the independence assumption, we can use the computationally simpler logit method. For those problems where the independence assumption makes sense, the methodology we describe would be useful.

Regarding the functional forms for the residuals u_1, u_2, u_3 we can assume them to be normally distributed and thus use the probit method to estimate the parameters in equations (2.7) to (2.9), or we can assume them to have a sech^2 distribution and thus use the logit method to estimate the parameters. Since we are assuming mutual independence between u_1, u_2, u_3 it does not make much difference. If we allow for correlations among the residuals, the multivariate normal distribution would be more appropriate. Because of the independence assumption we chose to estimate these equations by the logit method.

As for the output equation, we assume the residuals u in equations (2.6) to be $IN(o,\sigma^2)$.

One method that suggests itself is to estimate equation (2.6) by ordinary least squares get an estimate $\hat{\gamma}$ of γ substitute it in equations (2.7) to (2.9) and get estimates of $(\alpha_1, \alpha_2, \alpha_3, \beta_1, \beta_2, \beta_3)$ by estimating these equations by the logit method.

It is easy to see that the resulting estimates are consistent. They are not efficient because of cross-equation constraints implied by the occurrence of γ in all the equations.

Table 1 presents the OLS estimates of the output equation (2.6) and Table 2 presents the logit estimates of the parameters in equations (2.7) - (2.9). In the OLS estimation of the output equation, note that the coefficients that are significant are Age, IRRIG and SCHOOLING and some coefficients like CROP have the wrong sign.

The logit estimates are those obtained by estimation of the equations (2.7) to (2.9) after substituting the least squares estimate $\hat{\gamma}$ for γ. Thus, only the parameters (α_i, β_i) are estimated. The standard errors are not the correct ones since they are conditional on $\hat{\gamma}$. Note that the β coefficients are all significant.

3. Maximum Likelihood Estimation

The estimates presented in the previous section are consistent but not efficient. We will now discuss the ML estimation of the model where the cross-equation restrictions are imposed. The contribution to the likelihood function from the output variable is:

$$\frac{1}{\sigma} \exp\left[-\frac{1}{2\sigma^2}(y - \alpha - \delta A - Z\gamma)^2\right]$$

Since Prob. $(I_j = 1) = \dfrac{\exp(\alpha_j + \beta_j\ Z\gamma)}{1 + \exp(\alpha_j + \beta_j\ \ Z\gamma)}$ for $j = 1, 2, 3$

the contribution to the likelihood function from the j-th dummy variable is:

$$\left[\frac{\exp(\alpha_j + \beta_j\ Z\gamma)}{1 + \exp(\alpha_j + \beta_j\ Z\gamma)}\right]^{I_j} \left[\frac{1}{1 + \exp(\alpha_j + \beta_j Z\gamma)}\right]^{1-I_j}$$

$$= \frac{[\exp(\alpha_j + \beta_j Z\gamma)]^{I_j}}{1 + \exp(\alpha_j + \beta_j Z\gamma)}$$

The log-likelihood is given by

$$\text{Log } L = \text{const.} - \frac{n}{2} \text{Log } \sigma^2 - \frac{1}{\sigma^2} \sum_{i=1}^{n} (y_i - \alpha - Z_i\gamma - \delta A_i)^2$$

$$+ \sum_{i=1}^{n} \sum_{j=1}^{3} I_{ji}\ (\alpha_j + \beta_j\ Z_i\gamma)$$

$$- \sum_{i=1}^{n} \sum_{j=1}^{3} \text{Log } [1 + \exp\ (\alpha_j + \beta_j\ Z_i\gamma)] \tag{3.1}$$

Maximizing first with respect to σ^2 we get

$$\hat{\sigma}^2 = \frac{1}{n} \sum_{i=1}^{n} (y_i - \alpha - Z_i\gamma - \delta A_i)^2 \tag{3.2}$$

Substituting this we get the concentrated likelihood function as:

Table 1: OLS ESTIMATION OF THE OUTPUT EQUATION

Variable		Coefficient	t-ratio
Intercept	(α)	-31.482	--
Area	(δ)	25.243	22.13
Owner	(γ_1)	- 7.788	- 1.72
Age	(γ_2)	3.023	1.79
School	(γ_3)	1.951	2.91
Co-op	(γ_4)	9.002	1.80
Irrig.	(γ_5)	15.948	2.50
Crop	(γ_6)	2.113	.33

$R^2 = 0.43$ No. of obs. = 800.

Table 2: TWO STAGE LOGIT ESTIMATES

	HYBRID	CHM	LAND
α	-2.253	.590	-1.780
β	.0407	.0273	.0369
	(t = 5.21)	(t = 4.34)	(t = 5.37)

$$\text{Log } L^* = -\frac{n}{2} \text{Log } [\sum_{i=1}^{n} (y_i - \alpha - Z_i\gamma - \delta A_i)^2]$$

$$+ \sum_{i=1}^{n} \sum_{j=1}^{3} I_{ji} (\alpha_j + \beta_j Z_i\gamma)$$

$$- \sum_{i=1}^{n} \sum_{j=1}^{3} \text{Log } [1 + \exp (\alpha_j + \beta_j Z_i\gamma)] \quad (3.3)$$

Denoting $e_i = y_i - \alpha - Z_i\gamma - \delta A_i$ (3.4)

and $P_{ji} = \dfrac{\exp(\alpha_j + \beta_j Z_i\gamma)}{1 + \exp(\alpha_j + \beta_j Z_i\gamma)}$ (3.5)

we get

$\dfrac{\partial \text{ Log } L^*}{\partial\alpha} = 0$ gives $\Sigma e_i = 0$ (3.6)

$\dfrac{\partial \text{ Log } L^*}{\partial\alpha} = 0$ gives $\Sigma e_i A_i = 0$

$\dfrac{\partial \text{ Log } L^*}{\partial\alpha_j} = 0$ gives $\sum_i (I_{ji} - P_{ji}) = 0 \quad j = 1, 2, 3$ (3.7)

$\dfrac{\partial \text{ Log } L^*}{\partial\beta} = 0$ gives $\sum_i (I_{ji} - P_{ji}) (Z_i\gamma) = 0 \; j = 1, 2, 3$ (3.8)

$\dfrac{\partial \text{ Log } L^*}{\partial\gamma} = 0$ gives $\dfrac{1}{\hat\sigma^2} \sum_i e_i Z_i + \sum_i \sum_{j=1}^{3} \beta_j (I_{ji} - P_{ji}) Z_i = 0$ (3.9)

The matrix of second derivatives can also be easily derived but is omitted here.

The ML estimates are presented in Table 3. The iteration was started from the initial consistent estimates presented in Tables 1 and 2. To ensure that our conclusions do not rest entirely on the (linear) functional form, we also ran the equations with y = log output and A = log area.

Table 3: MAXIMUM LIKELIHOOD ESTIMATES

Figures in parentheses are asymptotic t-ratios.

Output Equation

Variable		y = output, A = Area	y = log Output, A = Log Area
A	δ	25.86 (22.06)	0.66 (26.22)
Owner	γ_1	0.33 (.21)	- .003 (.23)
Age	γ_2	0.09 (.16)	- .002 (.32)
Schooling	γ_3	0.87 (3.15)	.008 (2.85)
CO-OP	γ_4	5.94 (3.20)	.051 (2.90)
IRRIG	γ_5	27.34 (5.24)	.261 (5.36)
CROP	γ_6	-14.92 (-4.73)	- .137 (-4.56)
Intercept	α	- 8.30 (1.0)	4.02 (95.52)

Indicator Equations:

HYBRID	α_1	- .78 (-2.91)	- .65 (-2.40)
	β_1	.0840 (4.43)	8.93 (4.47)
CHM	α_2	1.58 (6.99)	1.63 (7.03)
	β_2	.0466 (3.48)	4.77 (3.39)
LAND	α_3	- .59 (-2.81)	- .52 (-2.47)
	β_3	.0559 (3.91)	5.86 (3.93)

The ML estimates are not much different from the OLS and Logit estimates presented in Tables 1 and 2. There are some differences in magnitudes and in sign. The coefficient of CO-OP is now significant and the coefficient of CROP has the correct negative sign and is significant. What is remarkable is the significant positive coefficient of the schooling variable in our results though admittedly the magnitude is small. The variable AGE, which is perhaps a good proxy for experience, is on the other hand not significant. The variables IRRIG and CO-OP which were significant in the Nerlove-Press analysis are also significant in our model. Given the different motivations for the two models, one cannot assign the same meanings to the coefficients. In the context of our model, what our results indicate is that the size of the farm, schooling, COOP, IRRIG and CROP are important determinants of "adoption of modern agricultural methods."

The fact that all the β coefficients are significant indicates that all the three dichotomous indicators: HYBRID, CHM and LAND, are reasonable indicators of the unobservable variables: "adoption of modern agricultural methods."

To check further sensitivity of our results, we re-estimated the model after introducing the dichotomous variables HYBRID, CHM, LAND and their interactions as explanatory variables in the output equation.

Note that the model is now a recursive type model discussed in Maddala and Lee (1976). We can again get consistent estimates of the parameters in the output equation by OLS estimation. We can, as before, use the ML method to get more efficient estimates of all the parameters.

The results of this estimation are reported in Table 4. These results are comparable to the results in the second column of Table 3, since they both have the same functional form. None of the interaction terms are individually significant. The conclusions regarding the other parameters are as before. Again, it should be noted that the schooling coefficient, though statistically significant, is small in magnitude. It implies that a one year increase in schooling results in a 0.5 percent increase in output per acre.

4. Models With Correlated Residuals

In the models discussed in the previous section we assumed the equation for the unobserved variable X^* to be non-stochastic. Note that equation (2.1) did not have an error term. We will now drop this assumption and re-write it as

$$X^* = Z\gamma + v \tag{4.1}$$

Substituting this in equations (2.2) and (2.5) we get

$$y = \alpha + \beta Z\gamma + \delta A + u + \beta v \tag{4.2}$$

$$y_1^* = \alpha_1 + \beta_1 Z\gamma + u_1 + \beta_1 v \tag{4.3}$$

$$y_2^* = \alpha_2 + \beta_2 Z\gamma + u_2 + \beta_2 v \tag{4.4}$$

$$y_3^* = \alpha_3 + \beta_3 Z\gamma + u_3 + \beta_3 v \tag{4.5}$$

Now note that even if the u's are independent, the residuals in equations (4.2) to (4.5) are not. Because of these correlations in the residuals, we have to drop the logistic model since the multivariate logistic model assumes fixed correlation coefficients. We will, therefore, have to assume that the residuals in equations (4.2) to (4.5) have a multivariate normal distribution.

Table 4: ML ESTIMATES WHEN THE OUTPUT EQUATION INCLUDED MAIN EFFECTS AND INTERACTIONS OF THE DUMMY INDICATOR VARIABLES

Equation	Variable		Estimate	t-ratio
Output Equation	Intercept	α	3.99	37.9
y = Log Output	A	(δ)	.65	26.1
A = Log Area.	Owner	(γ_1)	.001	.1
	Age	(γ_2)	- .002	.4
	School	(γ_3)	.005	2.2
	Co-op	(γ_4)	.035	2.3
	Irrig.	(γ_5)	.185	3.4
	Crop	(γ_6)	- .100	3.2
	I_1		.063	.6
	I_2		.107	1.2
	I_3		.073	1.3
	I_{12}		- .090	.8
	I_{13}		- .082	1.1
	I_{123}		- .012	.2
HYBRID Equation	α_1		- .59	2.05
	β_1		12.74	3.11
CHM Equation	α_2		1.67	6.87
	β_2		6.89	2.78
LAND Equation	α_3		- .48	2.18
	β_3		8.35	2.94

Since X^* is unobservable, we need some normalization. We can either assume $\beta = 1$ in the output equation (4.2) as before, or else normalize so that the residuals in equation (4.1) have a unit variance. Other normalizations are also possible. We can adopt whichever turns out to be convenient for the particular model. For the present we will use the normalization $\beta = 1$.

Note that the OLS estimates of (4.2) and the probit estimates of equations (4.3) to (4.5) are still consistent. To obtain efficient estimates, however, we have to use the ML method. In the above example this involves evaluation of multiple integrals in 3 dimensions. Though this can be done, we do not think it is worthwhile doing it for this data set.

In this case of one dummy indicator we can write the model as:

$$y = \alpha + Z\gamma + \delta A + u + v = \alpha + Z\gamma + \delta A + \varepsilon_1 \tag{4.6}$$

$$y_1^* = \alpha_1 + \beta_1 Z\gamma + u_1 + \beta_1 v = \alpha_1 + \beta_1 Z\gamma + \varepsilon_2 \tag{4.7}$$

$$I_1 = 1 \text{ iff } y_1^* > 0 \tag{4.8}$$

For convenience, we normalized the variance of ε_2 in equation (4.7) to be 1. The parameters in the covariance matrix we estimate are $\mathrm{Var}(\varepsilon_1) = \sigma_1^2$ and $\mathrm{Cov}(\varepsilon_1,\varepsilon_2) = \sigma_{12}$. Note that if we assume the residuals u and u_1 to be independent, then $\sigma_{12} = \beta_1\sigma_v^2$. We need not however make any such assumption.

The likelihood function for the model given by equations (4.6) to (4.8) is:

$$L = \prod_{I_1 = 0} \int_{-\infty}^{-\alpha_1 - \beta_1 Z\gamma} f(\varepsilon_1,\varepsilon_2) d\varepsilon_2 \quad \prod_{I_1 = 1} \int_{-\alpha_1 - \beta_1 Z\gamma}^{\infty} f(\varepsilon_1,\varepsilon_2) \, d\varepsilon_2$$

Writing $f(\varepsilon_1,\varepsilon_2)$ as $f(\varepsilon_1)\ f(\varepsilon_2|\varepsilon_1)$ we can simplify this likelihood function. Since only one integral is involved, we could easily maximize this likelihood function. The results were not different from those obtained earlier. Again schooling, CO-OP, IRRIG and CROP were significant variables and the other coefficients were not. The covariance σ_{12} was significant and positive in all cases.

Denoting by ρ the correlation coefficient between ε_1 and ε_2, the following are the estimates of ρ with their asymptotic t-ratios when we considered the output equation along with each of the three indicator variables, one at a time.

Indicator Var.	Estimate of ρ	t-ratio
CHM	.166	3.3
HYBRID	.097	1.8
LAND	.117	2.3

The correlations, though statistically significant, are not very high. As for the other coefficients, they are similar to those reported in Table 3 and hence are not reported here. The conclusions are the same as those from the results in Table 3 reported earlier. In view of this we did not pursue the elaborate calculations with trivariate integrals one would have to do to estimate the full model given by equations (4.2) to (4.5).

5. Conclusions

In this paper we have reformulated the Nerlove-Press model in terms of an unobserved underlying variable with a continuous and three dummy indicators. In the example on agricultural practices of Phillippino farmers, the underlying variable is "adoption of modern agricultural methods". Our basic problem is to study the determinants of this variable. In the case of the example on sexual attitudes of undergraduates at Northwestern University, the underlying variable is "sexual permissiveness" and our objective is to study the determinants of "sexual permissiveness."

~~We estimated~~ several models WERE ESTIMATED to study the determinants of the former latent variable using Mangahas' data that was used by Nerlove and Press. IT WAS ~~We~~ found that schooling, CO-OP and IRRIG were significant and positive and CROP was significant and negative and were the important determinants of "adoption of modern agricultural methods." The other explanatory variables were not significant. THE ~~Our~~ results are encouraging since the schooling variable was not significant in the Nerlove-Press analysis. In their analysis only IRRIG, CO-OP and AREA were significant. It should, however, be admitted that the schooling variable, though statistically significant, had a very small coefficient and the experience variable was not significant. Thus, the results reported here are not substantially different from those of Nerlove and Press. The formulation adopted here should, however, prove useful in several other appliations. The model we have estimated imposes a different and more readily interpretable structure on the data than that adopted by Nerlove and Press.

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